

Spaghetti cooking quality of waxy and non-waxy durum wheats and blends^{†‡}

Linda A Grant,* Douglas C Doeblert, Michael S McMullen and Nathalie Vignaux

USDA-ARS Hard Red Spring and Durum Wheat Quality Laboratory and Department of Plant Science, North Dakota State University, Fargo, ND 58105, USA

Abstract: Quality attributes of waxy durum wheat (*Triticum turgidum* L), milled semolina and cooked spaghetti were examined and compared with those of two non-waxy durum cultivars. With the exception of kernel hardness, wheat quality characteristics were similar for both waxy and non-waxy durum. Compared with average values obtained for durum wheat grown in North Dakota (USA) during the crop year 2000, the values obtained for the wheat used in this study were equal or better for most parameters evaluated. Semolina extraction for all samples was lower than the 2000 average of 62.6%. The waxy lines had higher ash, lower speck count, similar protein quantity, lower wet gluten and stronger mixograph curves than the non-waxy cultivars. Waxy durum semolina had higher lipid content, starch damage, stirring number and flour swelling values. Spaghetti made from waxy durum semolina had shorter cooking time, similar cooking loss and cooked weight and lower firmness values, which would be unacceptable by most standards. Spaghetti made from blends containing 20–80% waxy durum semolina were evaluated. Cooking time and firmness decreased and cooking loss increased as the amount of waxy semolina increased. Acceptable spaghetti was obtained using 20–40% waxy semolina blends, depending on the quality of the non-waxy blending material.

Published in 2004 for SCI by John Wiley & Sons Ltd

Keywords: waxy wheat; durum; spaghetti; processing; semolina; blends

INTRODUCTION

The waxy mutation in wheat results in the nearly complete elimination of amylose in the grain starch. Numerous efforts have recently been concentrated on the development of waxy hexaploid wheats.^{1–6} Yamamori and Nakamura⁷ produced the first waxy tetraploid wheat by crossing two wheat lines with the proper combination of null waxy genes. Efforts of the USDA-ARS and North Dakota State University (Fargo, ND, USA) have resulted in the development of waxy tetraploid durum wheat.⁸ Waxy durum wheat lacks functional genes for the waxy proteins in both the A and B genomes and, as a result, produces essentially amylose-free starch.⁹ Amylose is commonly lost from pasta during cooking,¹⁰ so it was hypothesised that amylose-free pasta might exhibit less cooking loss and result in pasta of higher quality. However, reduced amylose starch is associated with greater swelling capacity when heated in excess water and produces a softer gel as a result.^{9,11,12} This softening effect has been observed when bread was made using 100% waxy hexaploid wheat flour¹³ and waxy tetraploid wheat flour blends.¹⁴ Thus a counter-hypothesis to the one just presented is that waxy durum would produce

a softer, lower-quality pasta because of the altered rheological properties of the waxy starch.¹⁵ This study was designed to test these conflicting hypotheses.

The objective of this study was to test the effect of the waxy mutation on grain quality and pasta quality characteristics of durum wheat. We compared waxy lines with non-waxy durum cultivars and tested the effect of waxy/non-waxy semolina blends to determine the influence of amylose concentration in semolina on pasta cooking quality.

MATERIALS AND METHODS

Wheat samples

This investigation was divided into two parts involving plant material from two crop years. For the first part, two non-waxy durum wheat (*Triticum turgidum* L) cultivars (Ben and Munich) and three full waxy durum lines (designated as WX-4a, b and c) were grown in replicated plots at Fargo, ND, USA during the 2000 growing season. They were used to examine wheat and semolina quality and spaghetti cooking characteristics. Comparisons were made with durum wheat grown in North Dakota during 2000 and reported in the crop

* Correspondence to: Linda A Grant, USDA-ARS Hard Red Spring and Durum Wheat Quality Laboratory, Fargo, ND 58105, USA
E-mail: grantl@fargo.ars.usda.gov

[†]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product to the exclusion of others that may also be suitable

[‡]This article is a US Government work and is in the public domain in the USA

(Received 7 March 2003; revised version received 11 July 2003; accepted 29 September 2003)

quality survey.¹⁶ The second part was a blending study to determine the effect of amylose concentration in semolina on pasta quality. For this part of the study, non-waxy cultivars (Ben and Maier) were used as the base material, and a composite of individual WX-4 waxy durum lines obtained from the Fargo location, grown in 2001, was added in proportions ranging from 0 to 80%.

The three waxy durum lines used in these experiments were derived from an initial cross of the partial waxy (A and B genome) hard red winter wheat lke and durum wheat Ben. The sibling full waxy lines were derived from the fourth backcross to the recurrent parent Ben and embody 97% reconstituted durum background.¹⁴

Physical and chemical tests

Wheat

Test weight was determined on cleaned wheat using AACC Approved Method 84-10.¹⁷ Kernel size distribution was determined on 100 g of wheat according to the method of Shuey.¹⁸ 1000-Kernel weight was determined on 10 g of wheat using an electric seed counter (Seedburo Equipment Co, Chicago, IL, USA). Ash was determined using AACC Approved Method 08-01.¹⁷ Protein was measured by AACC Approved Method 46-30 (FP 428, Leco Corp, St Joseph, MI, USA).¹⁷ Wheat hardness was measured using an InfraAnalyser 400 (Technicon Instruments Corp, Tarrytown, NY, USA) according to AACC Approved Method 39-70A.¹⁷ Stirring number (SN) was determined using a Rapid Visco Analyser (RVA) 4 (Newport Scientific, Warriewood, NSW, Australia) according to AACC Approved Method 22-08.¹⁷

Wheat milling

Using a three-step tempering schedule, cleaned wheat was tempered to 17.5% moisture over a 48 h timeframe and milled on a Buhler pneumatic experimental mill (Buhler-Miag, Minneapolis, MN, USA) fitted with two laboratory-scale purifiers (AACC Approved Methods 26-10A and 26-41 respectively).¹⁷

Semolina

Moisture, ash, protein, lipids, stirring number and wet gluten were measured according to AACC Approved Methods 44-15A, 08-01, 46-30, 30-25, 22-08 and 38-12A respectively.¹⁷ Starch damage was determined using an enzymatic digestion assay kit (Megazyme International, Wicklow, Ireland) according to the method of Gibson *et al.*¹⁹ Speck count was determined according to the method of Dexter and Matsuo,²⁰ modified to report the average of triplicate counts per 10 in². Semolina colour was evaluated using a Minolta CR310 colour difference meter (Minolta Corp, Ramsey, NJ, USA). Readings of the L^* (brightness) and b^* (yellowness) values were determined as described by Walsh.²¹ Flour swelling value was determined on the semolina according to the method of Crosbie¹¹ as modified by Crosbie and Lambe²² and

reported as ml g⁻¹ dry semolina. Amylose content was determined according to the method of Grant *et al.*²³ Mixograms were obtained using AACC Approved Method 54-40A.¹⁷ An empirical score of 1–8 was assigned to each mixogram based on comparisons with reference mixograms. Higher values indicate stronger mixing characteristics.

Semolina blends

Blends (1000 g) made by adding 20, 40, 60 and 80% waxy (WX-4) durum semolina to non-waxy cultivars (Ben and Maier) were thoroughly mixed in an 8 qt capacity cross-flow blender (Patterson-Kelley Co, East Stroudsburg, PA, USA) for 20 min.

Pasta processing

Semolina was processed into spaghetti using a De Maco continuous semi-commercial-scale vacuum pasta extruder (DeFrancisci Machine Corp, Brooklyn, NY, USA) under conditions similar to those described by Walsh *et al.*²⁴ and in AACC Approved Method 66-41.¹⁷ The actual conditions for dough extrusion were: screw rotation speed, 20–29 rpm; vacuum, 12–15 psi; jacket temperature, 46–48 °C. The spaghetti was dried in a laboratory pilot-scale drier (Standard Industries, Inc, Fargo, ND, USA) using a two-stage high-temperature drying cycle. In the first stage the cabinet temperature was raised from 30 to 55 °C in the first hour and held at 55 °C for 3 h. In the second stage the cabinet temperature was raised to a maximum of 70 °C and gradually lowered to 45 °C for a total drying time of 12 h. Relative humidity was lowered in increments from 80 to 30%.

Pasta quality

Spaghetti colour

Dry and cooked spaghetti colour was determined using a Minolta CR310 colour difference meter equipped with a 50 mm diameter measuring head. Colour scores, modified for the Minolta colour difference meter by Debbouz,²⁵ were obtained for L^* (brightness) and b^* (yellowness).

Cooked weight

A modification of the procedure described by Dick *et al.*²⁶ was used for assessment of cooking quality. Spaghetti (10 g) was broken into lengths of approximately 5 cm and cooked on a hot plate (Thermolyne Corp, Dubuque, IA, USA) in glass beakers containing 300 ml of boiling distilled water. Each spaghetti sample was cooked to its optimal cooking time. Optimal cooking time was defined as the time required for the white core in the centre of the spaghetti strand to disappear. Optimal cooking time was determined on a separate 10 g cooked sample by removing a strand from the cooking water at 30 s intervals and crushing it between two plexiglass plates. After cooking, the spaghetti strands were rinsed with distilled water (25 °C) into a Buchner funnel, allowed

to drain for 2 min and then weighed. Results were reported in grams.

Cooking loss

The combined cooking and rinse water was collected in a tared beaker, placed in an air oven at 110 °C and evaporated to dryness. The residue was weighed and reported as a percentage of dry (as is) spaghetti.²⁶

Firmness

Spaghetti firmness was assessed on the cooked samples using a TA-XT2 texture analyser (Texture Technology Corp, Scarsdale, NY, USA) according to AACC Approved Method 66-50.¹⁷ The texture analyser was equipped with a custom-made plexiglass tooth, described by Walsh²⁷ and later modified by Oh *et al.*²⁸ Results were measured in triplicate and the means obtained were reported in g cm⁻¹. Higher values indicate firmer pasta.

Statistical analysis

A complete randomised block design with three replicates was used for both growing years, with samples grown in 2001 pooled. Data were statistically analysed using one-way analysis of variance (ANOVA) and pairwise multiple comparison (Tukey test) (Statistix 7, Analytical Software, Tallahassee, FL, USA). All data were collected in at least triplicate and averaged unless otherwise noted.

RESULTS AND DISCUSSION

Wheat characteristics of the non-waxy cultivars and waxy lines grown in 2000 are shown in Table 1. Test weights were similar for all samples, with only WX-4c having a significantly lower test weight than the other samples. Test weights were higher than the 2000 North Dakota state average of 58.5 lb bu⁻¹.¹⁶ Based on test weight alone, all samples fell into the US grain grading classification of US # 1 Durum.¹⁶ Subclasses based on vitreousness were not determined. Unlike non-waxy durum wheat kernels, which are translucent, waxy durum wheat kernels are opaque and resemble non-vitreous kernels. This trait appears to be caused by the waxy mutation.

Kernel size distribution of medium and large kernels, averaged across all samples, was higher (38%) and lower (54%) respectively when compared with the 2000 North Dakota state averages of 37 and 56%.¹⁶ Munich was the only sample that had a significantly higher percentage of medium kernels (51%) and a significantly lower percentage of large kernels (39%) compared with the other samples. Of the waxy lines, WX-4b had a significantly higher percentage of large kernels (61%) and a significantly lower percentage of medium kernels (32%). For all samples the percentage of small kernels (data not shown) was low. Matsuo and Dexter²⁹ stated that semolina milling yield is affected only when the small-kernel percentage is high.

Average 1000-kernel weight for all samples was higher (34.8 g) than the 2000 North Dakota state average of 33.1 g.¹⁶

Ash and protein were higher for all samples compared with the state averages of 1.72 and 14.4% respectively. Protein ranged from 14.9 to 15.9% and showed significant differences among samples. Ash content ranged from 1.98 to 2.07% and was not significantly different for all samples except Ben.

Kernel hardness values also showed that Ben was significantly harder than Munich and the waxy lines. Although these values do not indicate kernel vitreousness (translucency or starchiness) of the samples, they usually predict milling performance in terms of semolina yield.

Stirring number (SN) values for all samples indicated no amylase activity present. Using regression analysis for SN versus falling number (FN), Ross *et al.*³⁰ found that an SN of 120 Rapid Visco Units (RVU) correlated with an FN of ~350 s. The SN values obtained for the present samples fell into an FN range of 335–345 s (data not shown), which was higher than the 2000 North Dakota state average of 193 s. For this investigation, SN was used in place of FN, because Graybosch *et al.*³¹ reported that waxy wheat samples behave differently from non-waxy wheat when using the FN test owing to the absence of amylose. The FN test subjects a sample to high heat (>95 °C) immediately. For waxy wheats, this temperature is too high. With shear, waxy wheat samples attain peak viscosity earlier (80 °C) and, by the time the sample reaches 95 °C, the slurry has

Table 1. Physical and chemical properties of non-waxy and waxy durum wheat^a

Sample	Test weight (lb bu ⁻¹)	Kernel size distribution (%)		1000-Kernel weight (g)	Ash (%) ^b	Protein (%) ^b	Kernel hardness	Stirring number (RVU) ^b
		Medium	Large					
Ben	60.6a	34bc	60a	36.8a	1.98b	15.3bc	132.0a	110b
Munich	60.4a	51a	39c	32.5c	2.05a	14.9d	123.0b	105b
WX-4a	60.3ab	38b	54b	33.3c	2.04ab	15.1c	116.0b	105b
WX-4b	60.1ab	32c	61a	35.6b	2.07a	15.9a	116.0b	108b
WX-4c	59.8b	36b	56b	35.6b	2.03ab	15.4b	118.5b	119a

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b 14% moisture basis.

completely broken down owing to the fragility of the starch structure.¹⁵ These data indicate that SN is an acceptable alternative to FN for evaluating sprout damage in waxy wheat.

Semolina extraction from the non-waxy cultivars and waxy lines (Table 2) was lower than the 2000 North Dakota state average of 62.6%.¹⁶ The slightly lower extraction of the waxy lines may be due to a combination of several factors. The inherently softer nature of the waxy wheat samples, as indicated by their hardness values, may be partly responsible. However, grain hardness of waxy wheat has been reported not to be a factor for low yields.³² Ash content was equal to the state average of 0.76% for the non-waxy cultivars, but significantly higher (0.83–0.85%) for the waxy lines. Although ash content is inherently higher in the endosperm of durum wheat than in that of other hard wheat types, the higher amounts obtained for the waxy lines appear to be a consequence of the waxy trait. Judging from the lower speck count of each WX-4 sample, it seems unlikely that mill streams contained significant amounts of bran. Although ash content was higher for the waxy lines, speck count was lower than for the non-waxy cultivars. Semolina speckiness tends to increase with increased extraction rate, which may explain the lower speck counts for the waxy lines.³² Protein content did not differ significantly among all samples and was not different from the 2000 state average of 13.4%. In general, protein content has a high correlation with gluten content, whereas pasta cooking quality is related to both protein content and gluten quality. Wet gluten is a quantitative measure of the gluten-forming proteins which are responsible for strength and pasta quality. Despite similar protein contents for all samples, wet gluten values for the two non-waxy semolina samples were slightly higher (38.8 and 40.0%) than for the waxy semolinas, which ranged from 35.5 to 36.4%. These data would suggest slightly better gluten quality for the non-waxy cultivars. The 2000 state average was 37.5%.¹⁶

Mixograms are rated on a scale of 1–8, with higher values indicating strong mixing characteristics. Generally, the mixogram provides important information about the gluten quality of the semolina, because parameters such as peak height and peak time can be measured, thus resulting in a score. Both non-waxy cultivars showed uncharacteristically weak

mixing curves and produced very low scores, whereas the waxy lines were classified with scores of 4 and 5, which were also lower than the 2000 state average of 6.¹⁶ A score of 6 would be considered moderately strong.

Table 3 indicates a significantly higher amount of lipid in the waxy durum semolina. Higher lipid content has been reported previously in waxy wheat and has been speculated to affect the millability of waxy endosperm lines.³¹ The higher lipid content of the waxy lines in this study could be another reason for the lower extraction rates.

Starch damage values for the waxy lines were twice those for the non-waxy cultivars. Higher starch damage in full waxy durum starch has been reported previously.^{9,15} Bettge *et al.*¹⁵ attributed the higher starch damage to the more fragile physical granule structure of waxy starch. They concluded that any process that subjects waxy starch to crushing or shearing will likely cause considerable starch damage. Thus more damage would be imparted to the waxy lines than to the non-waxy cultivars during the milling process. Stirring number values, as determined using the Rapid Visco Analyser, were significantly higher for the waxy lines than for the non-waxy cultivars. These data support the idea that lower amylose content is associated with higher peak viscosity.³³ Swelling values for the waxy semolina lines were significantly higher than for the two non-waxy cultivars. These values were in agreement with the higher SN values obtained for the waxy samples. Wheat flours with high swelling

Table 3. Lipid content, starch damage, stirring number and flour swelling values of non-waxy and waxy durum semolina^a

Sample	Lipid content (%) ^b	Starch damage (%) ^b	Stirring number (RVU) ^c	Flour swelling (ml g ⁻¹) ^c	Amylose content (%) ^d
Ben	1.08c	2.8b	124c	10.3c	26.1a
Munich	1.04c	2.6c	111d	10.2c	24.1a
WX-4a	1.27b	4.4a	188ab	19.5b	0.0b
WX-4b	1.42a	4.3a	184b	20.0a	0.0b
WX-4c	1.49a	4.3a	190a	19.1b	0.0b

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b Dry weight basis.

^c 14% moisture basis.

^d As is moisture basis.

Table 2. Milling characteristics of non-waxy and waxy durum semolina^a

Sample	Semolina extraction (%)	Ash (%) ^b	Speck count (per 10 in ²)	Protein (%) ^b	Mixogram classification (1–8)	Wet gluten (%) ^b
Ben	55.1	0.76b	13	13.7ab	3	40.0a
Munich	54.2	0.78b	12	13.6ab	2	38.8a
WX-4a	54.7	0.85a	9	13.7ab	4	34.1c
WX-4b	53.6	0.83a	11	14.0a	5	36.4b
WX-4c	51.3	0.83a	9	13.6b	5	33.5c

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b 14% moisture basis.

values have been associated with desirable soft and elastic eating quality of Japanese white salted noodles and high-quality Korean white salted noodles.³⁴

Cooking quality

Spaghetti was processed from the non-waxy and waxy durum semolina and cooked to ascertain cooking quality factors. Each spaghetti sample was cooked to its individual optimal cooking time as described above. The two parameters that showed significant differences between the spaghetti made from non-waxy semolina and that made from waxy semolina were spaghetti colour and firmness (Table 4). The colour of the uncooked spaghetti made from waxy semolina was brighter, as indicated by the higher L^* values, but was also significantly less yellow, as indicated by the lower b^* values, than that of the spaghetti made from non-waxy semolina. These results are typical, in that a lower b^* value will inevitably give a higher L^* value, and are generally associated with kernel vitreousness. The higher brightness scores of the spaghetti made from waxy durum semolina may also reflect the lower speck counts of the waxy semolina. Lower speck counts are obtained when the extraction rate is also lower. Semolina extraction rate is negatively correlated with spaghetti brightness, therefore higher spaghetti brightness is also related to lower extraction rate.³⁵ Lower firmness values (Table 4) were obtained for the cooked spaghetti made from waxy semolina. The absence of amylose in the starch of the waxy semolina samples, which contributes to the higher swelling volume of these samples, is most likely the reason for the lower firmness values. Dexter and Matsuo³⁶ showed by reconstitution experiments that pasta firmness and resilience are positively related to starch amylose content. Considering that the 2000 state average for firmness was 6.7 g cm^{-1} , firmness values in the range of $5.3\text{--}5.6 \text{ g cm}^{-1}$ associated with the waxy samples would be considered unacceptable to most US consumers, who prefer pasta that is 'al dente' (having some firmness to the bite). The softer mouth feel of the pasta derived from the waxy durum may be more appropriate for Asian noodles. Cooked weight and cooking loss for all samples were similar. The lack of differences in cooking loss was surprising and disproved our hypothesis that spaghetti made from

amylose-free semolina would exhibit less cooking loss and result in pasta of higher quality.

Cooking quality of blends

Taking the cooking information obtained from the previous experiment into account, we developed a blending study to specifically test the effect of amylose concentration on pasta quality. Blends were made using two cultivars (Ben and Maier) as blending medium. These two cultivars were rated as having 'excellent' quality factors in the US Northern Grown Regional Quality Report.³⁷ The blends, containing a composite of 20–80% WX-4 durum semolina, were processed into spaghetti and cooked to optimal cooking time for each individual sample. Table 5 shows that there were significant differences between the two non-waxy cultivars for all parameters except cooking loss and cooked spaghetti L^* (brightness) value. Cultivar variations such as these are to be expected. Of the two non-waxy cultivars, Ben was able to support a higher percentage of waxy semolina (60% as opposed to 40% for Maier) and produce acceptable pasta, using firmness as a criterion, based on the 2001 state average of 6.1 g cm^{-1} .³⁷

Optimal cooking time and firmness decreased as the percentage of waxy semolina increased in the blends. Cooked weight was similar for each group of blends; however, cooking losses were significantly higher for blends containing from 20 to 40% Ben and from 20 to 60% Maier. The cooked spaghetti L^* (brightness) values were similar for all samples, but b^* (yellowness) values were higher for the samples containing Maier than for those containing Ben. These data would support the 2001 state average for pasta colour of Maier being higher than that of Ben.³⁷

The cooking quality results obtained for both studies were consistent considering that the waxy durum was obtained from two different crop years, but grown at a single location. Therefore these data represent environmental replicates. Results from both studies indicated that waxy durum imparted an unacceptable character to the quality of the pasta produced.

CONCLUSIONS

Insignificant differences in wheat quality parameters were obtained for the waxy and non-waxy durum

Table 4. Cooking quality data of spaghetti made from waxy and non-waxy semolina^a

Sample	Cooking time (min)	Cooked weight (g)	Cooking loss (%)	Firmness (g cm^{-1})	Cooked spaghetti colour	
					L^*	b^*
Ben	10.5a	30.5a	5.1b	6.7a	60.4c	43.4b
Munich	9.5b	28.9b	5.2ab	6.3a	60.5c	47.4a
WX-4a	8.5d	28.4b	5.4a	5.6b	62.0b	39.0c
WX-4b	9.0bc	29.1b	5.4a	5.3b	63.1a	39.6c
WX-4c	8.5c	28.6b	5.1b	5.4b	63.9a	39.8c

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

Table 5. Cooking quality data for spaghetti made from waxy/non-waxy semolina blends^a

Sample	Cooking time (min)	Cooked weight (g)	Cooking loss (%)	Firmness (g cm ⁻¹)	Cooked spaghetti colour	
					L*	b*
<i>Ben (WX/N-WX)</i>						
0/100%	12.0a	29.7a	4.4h	9.4a	69.5bcd	22.1f
20/80%	11.5ab	29.6a	4.6fgh	8.5b	70.4a	22.4ef
40/60%	10.0d	29.0bc	4.8def	7.1c	69.7bc	23.0de
60/40%	9.5e	28.6cd	5.2c	6.8cd	69.1cd	22.8def
80/20%	9.0e	29.4ab	5.9a	5.4e	69.4ef	22.7def
<i>Maier (WX/N-WX)</i>						
0/100%	11.0bc	28.5cd	4.5gh	8.8b	69.7bc	28.4a
20/80%	10.5cd	28.8c	4.8efg	7.1cd	70.0ab	27.7a
40/60%	10.5d	28.9bc	5.0cde	6.6d	69.4bcd	26.8b
60/40%	9.5e	28.3d	5.1cd	5.6e	68.9de	24.5c
80/20%	9.0ef	28.2d	5.5b	5.2e	69.3cd	23.2d
<i>Waxy</i>						
100%	8.5f	28.6cd	5.8a	4.5f	67.8f	23.3d

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

wheat samples. Slight variations could be due to the different cultivars and lines used. In most cases, values obtained were equal to or better than the North Dakota state averages for the same growing year.¹⁶ Waxy durum semolina had significantly higher ash content but lower speck count than non-waxy durum semolina, which indicated that the higher mineral content was not due to excess bran contamination. Protein quantity was similar for all samples, but protein quality was slightly lower for the waxy semolina, as indicated by lower wet gluten values. Waxy semolina had higher lipid, starch damage and stirring number values than the non-waxy semolina samples. Cooking quality of the spaghetti made from the waxy and non-waxy semolina in the first study indicated similar cooked weight and cooking loss but significantly different firmness and uncooked spaghetti colour values. In the second study, marginally acceptable spaghetti was made from blends of 20% waxy and 80% non-waxy semolina. Data showed that Ben could support higher amounts of waxy semolina (up to 60%) and still produce acceptable spaghetti based on the North Dakota state 2001 average for firmness.³⁷

The primary objective of this investigation was to determine the effect of the waxy mutation in durum on pasta quality. We found that 100% waxy semolina produced unacceptably soft spaghetti, which we attribute to the absence of amylose in the waxy durum starch. The similarity in cooked weight for both waxy and non-waxy spaghetti in both studies indicates that our second hypothesis was correct. The spaghetti derived from waxy durum does not absorb more water, therefore the less firm pasta obtained is due to the softness of the starch gel formed during cooking. More research is needed to answer questions concerning the biochemical differences between waxy and non-waxy durum and to utilise these differences to develop quality end-products.

ACKNOWLEDGEMENTS

The authors thank Angela Ostenson, Dehdra Pühr and Merle Skunberg for technical assistance.

REFERENCES

- 1 Yamamori M, Nakamura T and Nagamine T, Inheritance of waxy endosperm character in a common wheat lacking three *Wx* proteins. *Breed Sci* 45:377–379 (1995).
- 2 Nakamura T, Yamamori M, Hirano H, Hidaka S and Nagamine T, Production of waxy (amylose-free) wheats. *Mol Gen Genet* 248:253–259 (1995).
- 3 Kiribuchi-Otobe C, Nagamine T, Yanagisawa T, Ohnishi M and Yamaguchi I, Production of hexaploid wheats with waxy endosperm character. *Cereal Chem* 74:72–74 (1997).
- 4 Yasui T, Sasaki T, Matsuki J and Yamamori M, Waxy endosperm mutants of bread wheat (*Triticum aestivum* L.) and their starch properties. *Breed Sci* 47:161–163 (1997).
- 5 Graybosch RA, Waxy wheats: origin, properties and prospects. *Trends Food Sci Technol* 9:135–142 (1998).
- 6 Crosbie GB, Holding our edge in noodle wheat. *W Aust J Agric* 35:77–82 (1994).
- 7 Yamamori M and Nakamura T, Production of a waxy wheat by genetically eliminating *wx* proteins. *Gamma Field Symp* 33:63 (1994).
- 8 Hegstad JB, Kianian SF, McMullen MS and Doeblert DC, Development of waxy (low amylose) durum cultivars, in *Proceedings of the Ninth International Wheat Genetics Symposium*, Vol 4, Ed by Slinkard AE. University Extension Press, University of Saskatchewan, Saskatoon, pp 172–174 (1998).
- 9 Grant LA, Vignaux N, Doeblert DC, McMullen MS, Elias EM and Kianian S, Starch characteristics of waxy and nonwaxy tetraploid (*Triticum turgidum* L. var. durum) wheats. *Cereal Chem* 78:590–595 (2001).
- 10 Grant LA, Dick JW and Shelton DR, Effects of drying temperature, starch damage, sprouting, and additives on spaghetti quality characteristics. *Cereal Chem* 70:676–684 (1993).
- 11 Crosbie GB, The relationship between starch swelling properties, paste viscosity and boiled noodle quality in wheat flours. *J Cereal Sci* 13:145–150 (1991).
- 12 Morris CF, King GE and Rubenthaler GL, Contribution of wheat flour fractions to peak hot paste viscosity. *Cereal Chem* 74:147–153 (1997).

- 13 Morita N, Maeda T, Miyazaki M, Yamamori M, Miura H and Ohtsuka I, Dough and baking properties of high amylose and waxy wheat flours. *Cereal Chem* 79:491–495 (2002).
- 14 Bhattacharya M, Erazo-Castrejon SV, Doeblert DC and McMullen MS, Staling of bread as affected by waxy wheat flour blends. *Cereal Chem* 79:178–182 (2002).
- 15 Bettge AD, Giroux MJ and Morris CF, Susceptibility of waxy starch granules to mechanical damage. *Cereal Chem* 77:750–753 (2000).
- 16 North Dakota Wheat Commission (NDWC), US northern grown durum wheat. *Regional Quality Report* (2000).
- 17 AACC, *Approved Methods of the AACC*, 10th edn. American Association of Cereal Chemists, St Paul, MN (2000).
- 18 Shuey WC, A wheat sizing technique for predicting flour milling yield. *Cereal Sci Today* 5:71–72, 75 (1960).
- 19 Gibson TS, Qalla AJ and McCleary BV, An improved enzymatic method for the measurement of starch damage in wheat flour. *J Cereal Sci* 10:15–27 (1992).
- 20 Dexter JE and Matsuo RR, Effect of smudge, blackpoint and mildewed wheat. *Cereal Chem* 59:63–69 (1982).
- 21 Walsh DE, Measurement of spaghetti color. *Macaroni J* 52:20–22 (1970).
- 22 Crosbie GB and Lambe WJ, The application of the flour swelling volume test for potential noodle quality to wheat breeding lines affected by sprouting. *J Cereal Sci* 18:267–276 (1993).
- 23 Grant LA, Ostenson AM and Rayas-Duarte P, Determination of amylose and amylopectin of wheat starch using high performance size-exclusion chromatography (HPSEC). *Cereal Chem* 79:771–773 (2002).
- 24 Walsh DE, Ebeling KA and Dick JW, A linear programming approach to spaghetti processing. *Cereal Sci Today* 16:385–389 (1971).
- 25 Debbouz A, What's new in pasta color? *Pasta J* 76:31–32 (1994).
- 26 Dick JW, Walsh DE and Gilles KA, The effect of field sprouting on the quality of durum wheat. *Cereal Chem* 51:180–188 (1974).
- 27 Walsh DE, Measuring spaghetti firmness. *Cereal Sci Today* 16:202–205 (1971).
- 28 Oh NH, Seib PA, Deyoe CW and Ward AB, Noodles. I. Measuring the textural characteristics of cooked noodles. *Cereal Chem* 60:433–438 (1983).
- 29 Matsuo RR and Dexter JE, Comparison of experimentally milled durum wheat semolina to semolina produced by some Canadian commercial mills. *Cereal Chem* 57:117–122 (1980).
- 30 Ross AS, Walker CE, Booth RI, Orth RA and Wrigley CW, The rapid visco-analyser: a new technique for the estimation of sprout damage. *Cereal Foods World* 32:827–829 (1987).
- 31 Graybosch RA, Gang G and Shelton DR, Aberrant falling numbers of waxy wheats independent of α -amylase activity. *Cereal Chem* 77:1–3 (2000).
- 32 Yasui T, Sasaki T and Maysuki J, Milling and flour pasting properties of waxy endosperm mutant lines of bread wheat (*Triticum aestivum* L.). *J Sci Food Agric* 79:687–692 (1999).
- 33 Sasaki T, Yasui T and Matsuki J, Effect of amylose content on gelatinization, retrogradation, and pasting properties of starches from waxy and nonwaxy wheat and their F₁ seeds. *Cereal Chem* 77:58–63 (2000).
- 34 Lee C-H, Gore PJ, Lee H-D, Yoo B-S and Hong S-H, Utilization of Australian wheat for Korean style dried noodle making. *J Cereal Sci* 6:283–297 (1987).
- 35 Dexter JE and Matsuo RR, Effect of semolina extraction rate on semolina characteristics and spaghetti quality. *Cereal Chem* 55:841–852 (1978).
- 36 Dexter JE and Matsuo RR, Effect of starch on pasta dough rheology and spaghetti cooking quality. *Cereal Chem* 56:190–193 (1979).
- 37 North Dakota Wheat Commission (NDWC), US northern grown durum wheat. *Regional Quality Report* (2001).